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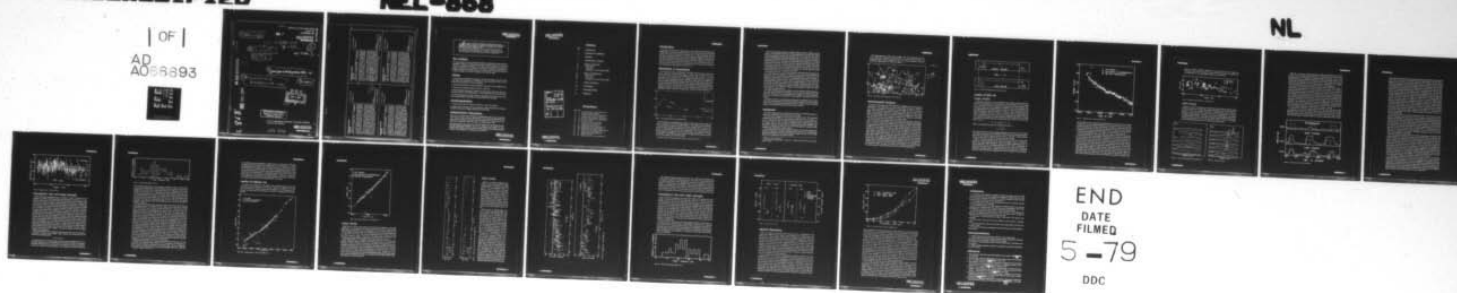
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<p>Navy Electronics Laboratory Report 868</p> <p>LORAD TEST OF 29-30 OCTOBER 1957 (U), by M. A. Pedersen. 20 p., 22 September 1958. CONFIDENTIAL</p> <p>A Loral echo-ranging test was made at a range of 88 miles, using a frequency of 700 cps. The target submarine recorded the transmissions from the echo-ranging submarine to aid in the analysis. Object of the test was to determine the characteristics of echo-ranging in the third convergence zone.</p> <p>Echoes were obtained over the 4000-yard range interval from 173.7 to 177.7 kiloyards for about 80 per cent of the transmissions. Unsuccessful transmissions could be attributed in general to high propagation losses. The scatter in range measurements was ± 100 yards. Target strengths were 25 db for beam aspect (270°) and 22 db for target aspect of 248°. It is estimated that, under favorable reverberation conditions, the effective echo-ranging width of the third convergence zone could be increased to about 8000 yards by a 10-db improvement in echo-to-noise ratio.</p> <p>AS 02101 NE 051600-847.61 (NEL L1-5)</p> <p>This card is CONFIDENTIAL</p>	<p>Navy Electronics Laboratory Report 868</p> <p>LORAD TEST OF 29-30 OCTOBER 1957 (U), by M. A. Pedersen. 20 p., 22 September 1958. CONFIDENTIAL</p> <p>A Loral echo-ranging test was made at a range of 88 miles, using a frequency of 700 cps. The target submarine recorded the transmissions from the echo-ranging submarine to aid in the analysis. Object of the test was to determine the characteristics of echo-ranging in the third convergence zone.</p> <p>Echoes were obtained over the 4000-yard range interval from 173.7 to 177.7 kiloyards for about 80 per cent of the transmissions. Unsuccessful transmissions could be attributed in general to high propagation losses. The scatter in range measurements was ± 100 yards. Target strengths were 25 db for beam aspect (270°) and 22 db for target aspect of 248°. It is estimated that, under favorable reverberation conditions, the effective echo-ranging width of the third convergence zone could be increased to about 8000 yards by a 10-db improvement in echo-to-noise ratio.</p> <p>AS 02101 NE 051600-847.61 (NEL L1-5)</p> <p>This card is CONFIDENTIAL</p>
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the problem

The work was done as part of the general problem to determine the characteristics of propagation, reflection, and diffraction (primarily at frequencies below 10 kc) and their relation to environmental conditions, and to determine echo properties of underwater targets. The application of this problem is the detection, tracking, and classification of underwater targets at long range. This report covers a Lorad echo-ranging experiment at 700-cps frequency in the third convergence zone (88-mile range).

results

1. Lorad echoes were obtained consistently in the third convergence zone for the first time. Echoes were obtained over the 4000-yard range interval from 173.7 to 177.7 kiloyards for about 80 per cent of the transmissions.
2. Unsuccessful transmissions could be attributed, in general, to high propagation loss.
3. The scatter in range measurements was about ± 100 yards.
4. Under favorable reverberation conditions the echo-ranging width of the third zone may be increased to about 8000 yards by a 10-db improvement in echo-to-noise ratio.
5. At 700-cps frequency the target strength as measured at the third zone was 25 db for beam aspect (270°) and 22 db for an aspect of 248° (22° off beam).

recommendations

1. Conduct similar tests in the third zone with bow or stern target aspects.
2. Conduct tests in the third zone under conditions of higher reverberation with special emphasis on the use of the higher resolutions on the FM system.

administrative information

This work was conducted under AS 02101, NE 051600-847.61 (NEL L1-5). The objectives of this study are closely related to NEL Problem E1-3 (Lorad) (NE 051600-847.19). This report covers an experiment conducted 29 and 30 October 1957, and was approved for publication 22 September 1958. The analysis was completed May 1958.

Ships participating in the sea test were USS BAYA (AGSS 318), USS TILEFISH (SS 307), and USS MARYSVILLE (PCE(R)857). The test was designed and conducted by Henry Westfall. Robert McBride, Charles Sturtevant, and Mrs. Grace Wofford assisted with data reduction. The final figures were prepared by Mrs. Wofford.

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introduction

This report is concerned with a deep water test of the NEL Lorad (Long Range Active Detection) sonar. A previously published report¹ covers work on Lorad from April 1954 to May 1956.* Sea tests of Lorad were stopped early in 1956 for submarine overhaul and various equipment modifications, and were resumed in September 1956. Some of the results of the deep water tests conducted since September 1956 were reported at the 15th Navy Symposium on Underwater Acoustics (1957). Echo-ranging in the third convergence zone was achieved during three different sea tests. The present report covers the most successful of these three tests. The primary objective of this test was to determine the characteristics of echo-ranging in the third zone.

description of experiment

The test was conducted in 2200-fathom water about 100 miles west of Point Conception, California. It consisted of two parts — a drift run and an oblique run. For the drift run the target submarine, USS TILEFISH (SS 307), took a position in the third convergence zone. This position was at a range of about 89 miles on a bearing of 292° T from the echo-ranging submarine, USS BAYA (AGSS 318). The TILEFISH then hovered at 100-foot depth with a heading of 202° T so as to maintain beam aspect with the echo-ranging path. The BAYA also hovered at 100-foot depth, adjusting heading as necessary in order to keep the target in the transmitting and receiving beams. Echo-ranging was continued in this manner for 4 hours. During this 4-hour period the range decreased by about 1 mile due to a difference in drift rate of the two submarines.

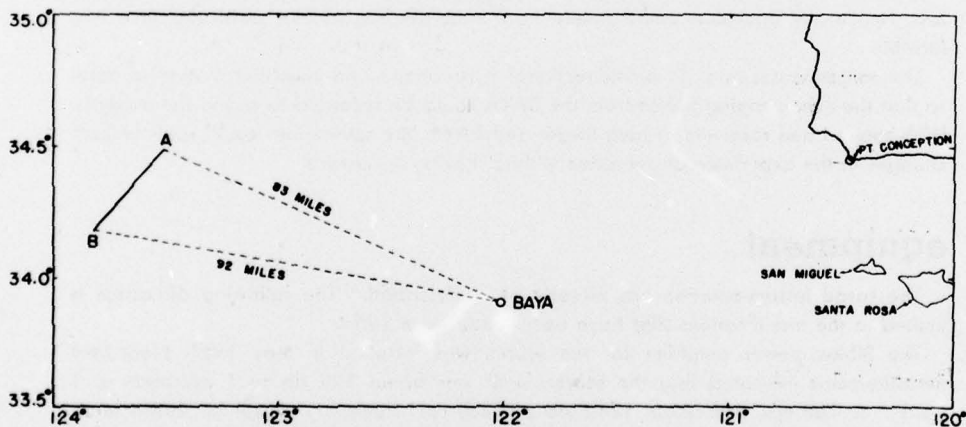


Figure 1. Map showing location of the experimental track

For the oblique run the TILEFISH took a position at point A at a range of about 83 miles on a bearing of 295° T from the BAYA (fig. 1). The TILEFISH then proceeded on a course of 220° T at a speed of 3 knots for 8 hours, arriving at point B at the end of the test. The range of point B was 92 miles on a bearing of 280° T from the BAYA. Thus 9 miles — a major portion of the third zone range interval — was traversed during this echo-ranging test. This oblique course was chosen because simple approach or recede courses present unfavorable bow or stern aspects. The aspects for this course vary from 15° off beam aspect to 30° off beam aspect.

* Superscript numbers indicate references which are listed at the end of this report.

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Most of the echo-ranging was done at 700-cps frequency; however, 1200 cps was also used for a brief period in the drift run. The pulse length used for the AM echo-ranging system was generally 3 seconds. The AM pulses were sent in groups of four, with a 7-second interval between the individual pulses within a group. The last AM pulse of the group was followed after about a 10-second interval by an FM pulse of 10-second length. This group of four AM pulses and one FM pulse was repeated every 5 minutes throughout the experiment. This group cannot be repeated more often than about every five minutes, because the round trip travel time to the third zone is about 216 seconds and the pulse group itself occupies almost 60 seconds. Thus, at least 276 seconds must be allowed between groups in order that a possible echo from the last pulse be returned before the first pulse of the next group is transmitted.

During the echo-ranging tests the target submarine transmitted station-keeping pulses of $\frac{1}{2}$ -second length at a frequency of 1130 cps. Six such pulses were transmitted per minute with even 10-second intervals between the beginning of successive pulses. An additional 2-second pulse was inserted at the beginning of each minute for purposes of checking ranges. By noting the time at which this 2-second pulse arrived at the BAYA and knowing that this pulse was sent out from the target exactly on a minute, the travel time between the BAYA and target could be obtained providing the true travel time were known within 60 seconds. This system of obtaining ranges achieved only limited success because of the difficulty in keeping the time aboard the BAYA and target synchronized for periods of hours.

The station-keeping pulses also provided a means of obtaining relative bearings to the target, and thus aided the Lorad operators in training the receiving beams on the target. The amplitude of the station-keeping pulses provided the one-way propagation loss. Hence, the operators could determine if echo-ranging at that particular time was feasible.

The target vessel had an omnidirectional hydrophone and amplifier system aboard, so that the echo-ranging pulses from the BAYA could be recorded to aid in the analysis. With sources and receivers at both target and BAYA, the submarines could communicate changes in the experimental operation without having to surface.

equipment

The Lorad instrumentation has already been described.* The following discussion is limited to the modifications that have been made since 1956.

The 30-kw power amplifier for the source was installed in May 1957. Near-field measurements indicated that the source level was about 129 db re 1 microbar at 1 yard** at 700 cps, and about 124.5 db at 1200 cps. However, as will be shown later, this value at 1200 cps seems too high. The proposed barium titanate transducer was not installed, because it was found that the Lorad source array gave satisfactory performance at frequencies as high as 2.4 kc. A complete discussion of the present Lorad receiving array is presented in another report.²

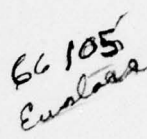
The tone (AM) system is the same as indicated in figure 17-5¹ with the exception that the output is recorded on two Edin 6-channel recorders rather than on a 13-pen Platen recorder. The FM system is the same as indicated in figures 17-6 and 17-7.¹ The noise system was not operative for the test of this report.

* Reference 1, Part IV, pages 13-32.

** In this report the reference level for all db levels is 1 microbar and all source levels are measured relative to 1 yard.

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environmental features

During the echo-ranging tests USS MARYSVILLE (PCE(R)857) made oceanographic measurements in the experimental area. These measurements consisted of hourly BT's and continuous measurement of temperature at eight depths by means of thermistor beads. These temperature measurements indicated a surface layer of about 110-foot depth. In some cases the temperature increased slightly with depth, so a fairly strong positive velocity gradient existed in the surface layer. Surface temperatures were about 59°F. The surface velocity was calculated to be 4926 ft/sec. There was a 2-to-3-foot swell with little wind wave. Wind velocities were under 5 knots.

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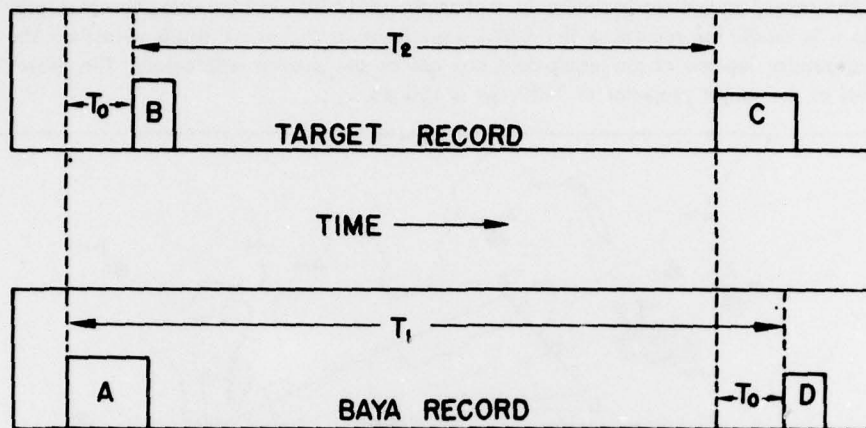


Figure 3. Schematic illustrating method of obtaining ranges

results of drift run

range results

As previously mentioned, it was not possible at sea to obtain accurate travel times, other than those obtained from echoes, because of the drift between the clocks aboard the two submarines. However, it is possible to compute the travel times accurately when the acoustic records from both submarines are available for use at the laboratory. This was accomplished by the method indicated in figure 3. Assume that the clock aboard the BAYA leads that aboard the target by an amount T_0 . Then the BAYA pulse (A), which is transmitted on the minute, is sent out T_0 seconds before the 2-second pulse (B) which is transmitted on the minute from the target. Consequently, the BAYA transmission (C) is received at the target T_0 seconds before the target transmission (D) is received at the BAYA. The quantities measured in the laboratory are T_1 and T_2 . If the true travel time is T , then

$$T = T_2 + T_0 \text{ and } T = T_1 - T_0$$

When T_0 is eliminated from these two expressions, the result is

$$T = \frac{T_1 + T_2}{2}$$

Thus, the true travel time T may be obtained independent of the value of T_0 . Since these travel times can be read only to the nearest 0.1 second because of the paper speed of the recorders, the relative ranges can be off as much as ± 80 yards. A mean horizontal velocity of 1621 yd/sec was used to convert travel times to ranges.

Figure 4 is the plot of ranges versus time of day for the drift test. The solid circles indicate the ranges measured from the one-way transmission records as indicated in figure 3. The open triangles indicate the range of the highest amplitude that occurs in each individual FM record. This highest amplitude may be an echo, reverberation, or noise burst. However, if such an observation does not fall in line with the ranges as indicated by the solid circles, it is evident that it must be reverberation or noise rather than echo. Two of the first three triangles from the left are examples of such non-echoes.

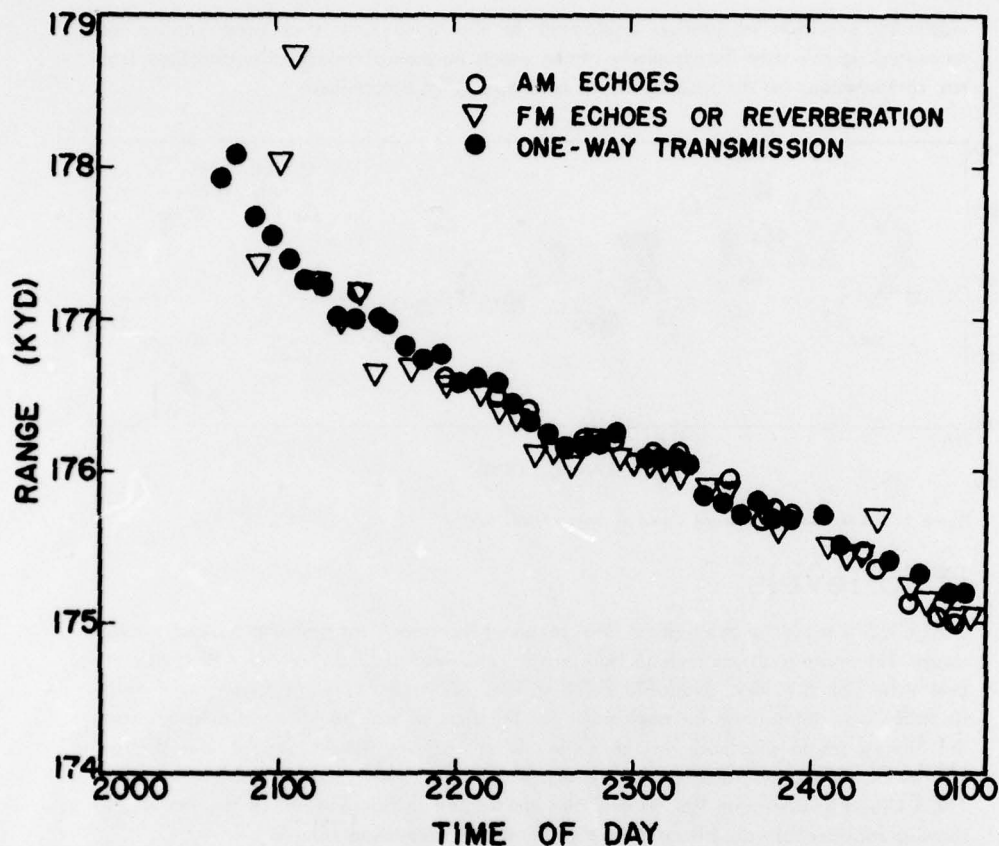


Figure 4. Computed range vs. time of day (drift run)

The FM ranges have been corrected for the Doppler shift caused by the rate of change of range. This rate was obtained independent of FM echoes by means of the one-way transmission observations. The open circles indicate the ranges as calculated from travel times measured from echoes on the AM system. Reverberation returns were also obtained on the AM system, but the corresponding ranges were not computed due to the difficulty of determining the leading edge of such returns, as will be discussed presently.

As will be indicated later, most of the eight open triangle or open circle observations at times less than 2145 are reverberation. A least-squares fit was made to a straight line for the data points from 2145 to 0100. The standard error of estimate of this line was 95 yards. However, since the drift was not truly linear, this value is somewhat high as a measure of the scatter. Hence the three methods of obtaining relative ranges appear to be consistent to within the equipment accuracy in measuring the travel times. It should be noted that figure 4 indicates nothing about absolute range accuracy. At these long ranges the ultimate limitation on range accuracy is determined by the accuracy of the value chosen for the mean horizontal velocity rather than by the accuracy of the travel time measurement. For example, if the mean horizontal velocity had been chosen as 1622 yd/sec rather than 1621 yd/sec, all ranges would be increased by about 110 yards. Tests have been started at NEL in which absolute measurements of range will be

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made by precision navigation equipment at the same time that echo ranges are measured. In this way the accuracy of the mean horizontal velocity, as obtained from ray computations for the velocity-depth profile, can be determined.

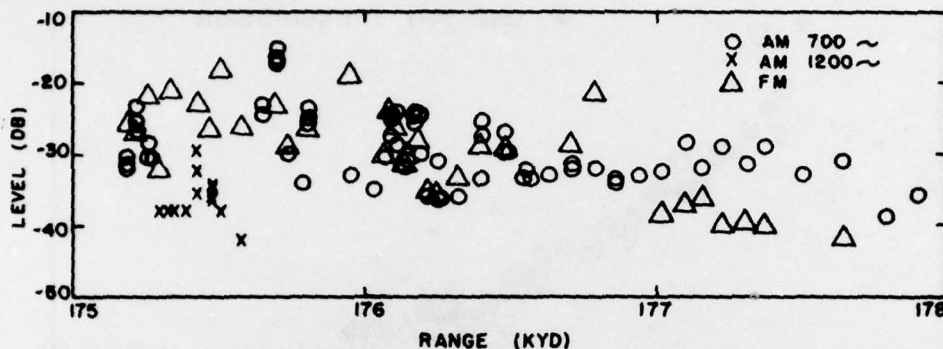


Figure 5. Peak level of returned signal vs. range (drift run)

echo levels

Figure 5 is a plot of the highest level received from each transmission plotted against range. These observations include both echoes and background. For the AM system the best echo for the nine available combinations of three receiving beams and three Dopplers was determined for each pulse. In the case of AM background measurements the highest single amplitude in the region where echoes should appear was plotted. For the FM the highest value on each sweep was plotted. Note that the FM levels beyond 176.8 kiloyards are quite low. This is also the region in figure 4 where the FM ranges showed considerable departure from the one-way transmission ranges.

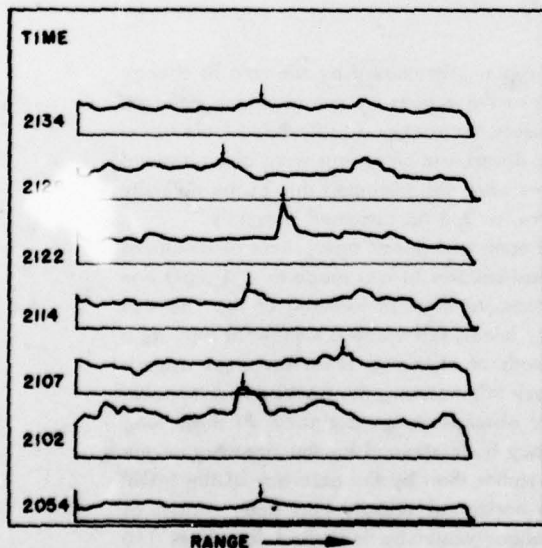


Figure 6A. FM record of reverberation and a possible echo

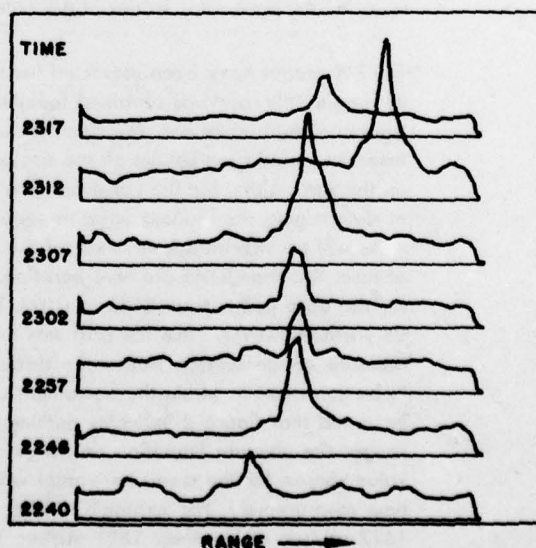


Figure 6B. FM record of echoes

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Figure 6A is a tracing of the FM records for the first seven transmissions of the drift run. This covers the range interval greater than 176.8 kiloyards. No range scale is indicated because of the complication of different resolutions and delay times for each transmission. The arrow indicates the observations which were recorded in figures 4 and 5. Of all these observations the one at 2122 is the most likely looking echo. Figure 4 indicates that this observation, the fourth from the left, is a possible echo. It is probable that the remaining observations are all reverberation or noise background.

Figure 6B is a tracing of the FM records covering the target movement from 176.1 to 175.9 kiloyards. The apparent erratic range movement of the echo is due to different resolutions and delay times for the various traces. This set was chosen for simplicity of record and does not represent the best echoes obtained on this test. The best echo was 5.5 db higher than that for 2312. On the basis of measured ranges and appearance of the records it was determined that of the 28 FM pulses transmitted at ranges between 175.0 and 176.8 kiloyards, 26 echoes were received. One echo was missed because the fixed delay time was set too far off for the echo to appear on the trace. The other missing echo was masked by a large burst of noise or reverberation. The average echo level was -27 db. The average level of those six FM transmissions, at ranges greater than 176.8 kiloyards, classified as non-echoes was -39.5 db, with a standard error of 0.7 db. The ambient noise level on the FM system was about -41.5 db.

It is somewhat more difficult to classify echoes on the AM system, because the ranges are measured by means of the leading edge of the echo rather than by the peak amplitude as with the FM system. Figure 7 is a tracing of three AM records of echoes and reverberation. Only the portion of the record in the vicinity of echo return is shown. The time on the abscissa is measured relative to the time of transmission of the first pulse.

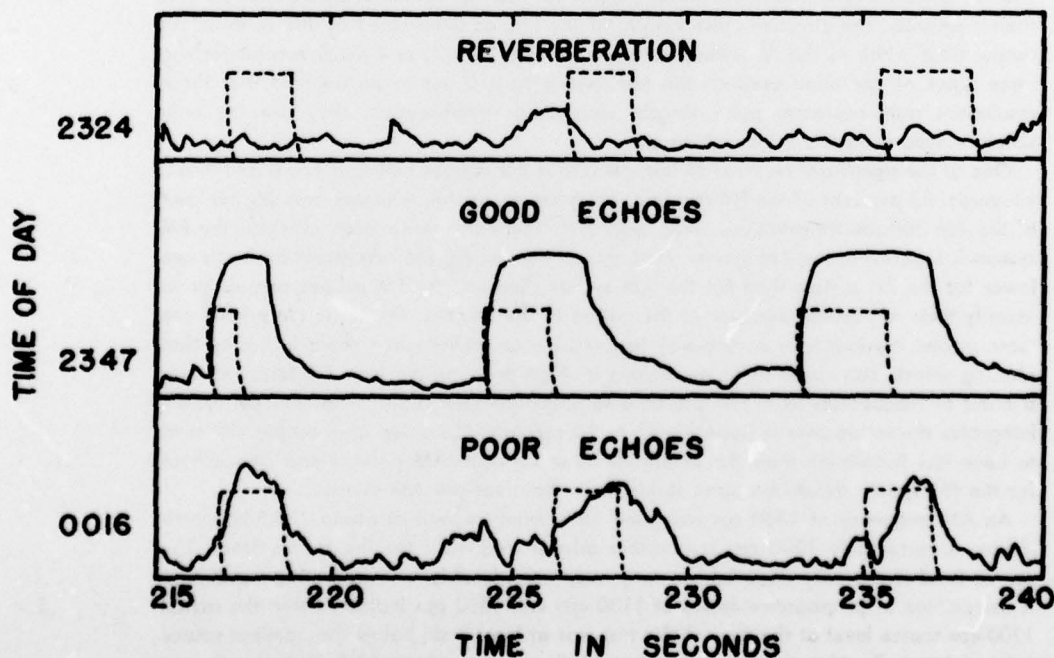


Figure 7. AM record of echoes and reverberation

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The dashed lines have been added to indicate the spacing and length of the transmitted pulses. The time position of the dashed pulses was determined by the travel time as obtained from the one-way transmission observations. The amplitude of these dashed pulses has no significance. The gain settings are the same for all three samples. The tops of the good echoes are squared off considerably because the amplifiers are overloaded by about 10 db as was determined from magnetic tape recordings which were not overloaded. The reverberation sample is easy to classify as such because the received signals do not have the proper time relationship with the transmitted pulses. The poor echo example indicates that even with fairly good echo-to-background ratios, the echo may not retain sufficient pulse shape to enable the leading edge to be clearly distinguished. In figure 4 only those AM echo ranges were plotted where the leading edge was clearcut. Three other returns were classified as echoes on the basis of amplitude, pulse spacing, or general appearance, although they did not retain a pulse shape suitable for checking ranges. Thus of the 26 AM transmissions at 700 cps at ranges between 175.0 and 176.8 kiloyards, 17 returns were considered to be echoes while the other 9 echoes were either nonexistent or doubtful. In this case a transmission was considered to produce an echo if any one of the four pulses sent out returned an echo. The average level of all the 700-cps observations considered as non-echoes was -32.8 db with a standard error of 0.6 db. The ambient noise level at 700 cps was about -45 db in a 0.4-cps bandwidth filter.

Recall that the level of non-echoes for the FM system was -39.5 , some 6.7 db lower than the comparable value for the AM system. A Student's *t*-test indicated that this difference was significant at better than the 1-per-cent level. This difference agrees with reverberation tests conducted in March 1957 which indicated that the reverberation level for the FM system is from 5 to 10 db lower than that for AM pulses of 3-second length. This results because the effective pulse lengths for the FM system are considerably less than 3 seconds. The effective pulse length for the FM, as determined by the ratio of the output filter width to the FM sweep rate, was 0.125, 0.0417, or 0.0125 second for the three types of operation used on this test. Although it is not to be inferred that these resolutions truly represent pulse lengths controlling reverberation, they are the only simple values available for comparison.

One of the significant features of this test is that, for ranges between 175.0 and 176.8 kiloyards, 93 per cent of the FM transmissions were successful, whereas only 65 per cent of the AM 700-cps transmissions were successful. There are three ways in which the FM system is superior to the AM system. First, as just mentioned, the reverberation levels are lower for the FM system than for the AM system. Second, the FM echoes are easier to identify than AM echoes because of the nature of the records. Third, the FM echoes are more stable. Previous tests of one-way transmission to convergence zones indicated that phasing effects can cause nulls, or regions of high propagation loss. Transmission over a band of frequencies as in FM will tend to eliminate these nulls. Also, the FM system integrates the return over a pulse length of 10 seconds. This integrated output will tend to have less fluctuation than the amplitude of a 3-second AM pulse. Hence the echoes for the FM system should be more stable than those for the AM system.

An AM frequency of 1200 cps was tried for a brief interval at about 175.5-kiloyards range. Unfortunately 1200 cps is a rather critical frequency for the source level. The source level is not only doubtful but may vary considerably with operating conditions. A comparison of propagation losses at 1130 cps and 1200 cps indicated that the actual 1200-cps source level at the time of this test was at least 7 db below the nominal source level of 124.5 db. Also, the source level at 1200 cps was at least 12.5 db below that at 700 cps. Because of this doubtful source level, about all that can be said of the 1200-cps data is that three echoes were received out of seven transmissions.

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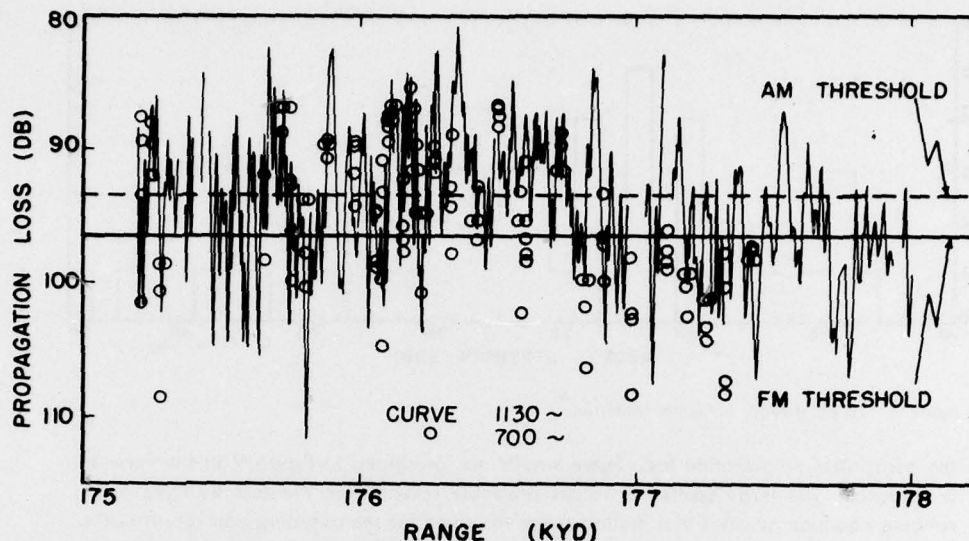


Figure 8. Propagation loss vs. range (drift run)

propagation loss and target strength

Figure 8 represents propagation loss as a function of range. The solid curve was obtained from 1130-cps pulses transmitted from the target and received by an omnidirectional hydrophone on the BAYA. These 0.5-second pulses were transmitted every 10 seconds. The values have been smoothed somewhat by computing a weighted (five point) running average of individual pulse amplitudes. This process has an advantage over averages over a range interval in that the rapid pulse-to-pulse fluctuation is filtered out, yet variation with range or temporal fluctuation of longer duration is preserved. The open circles represent the propagation loss at 700 cps for the BAYA AM echo-ranging transmissions as measured at the target. Unfortunately, similar values could not be obtained for the FM signals as the receiver system aboard the target had narrow filters to reduce the noise. The propagation loss pattern exhibits the characteristic rapid variation with range. Theoretical calculations indicate that this variation can be attributed to phasing effects between multiple arrivals.³ Note that the losses at 700 cps and 1130 cps are generally about the same for the first part of the zone, but the losses at 700 cps are somewhat higher than 1130 cps at ranges beyond 176.7 kiloyards. When positive-gradient surface channels are present, it is quite common for a higher frequency to have somewhat lower losses at the far side of the convergence zone. This is due to the fact that the sound travels partially in the surface channel in which the higher frequency has less damping.

Before the significance of the threshold values shown in figure 8 can be discussed it is necessary to consider target strengths. Target strengths were determined from the standard echo-ranging equation

$$E = S - 2H + T$$

E is the echo level, S is the source level, H is the one-way propagation loss, and T is the target strength. For each echo obtained on the AM system a value of H was determined from measurements on the target of the same pulse which returned to the BAYA as the echo. A value of the target strength, T , was computed for each echo level and

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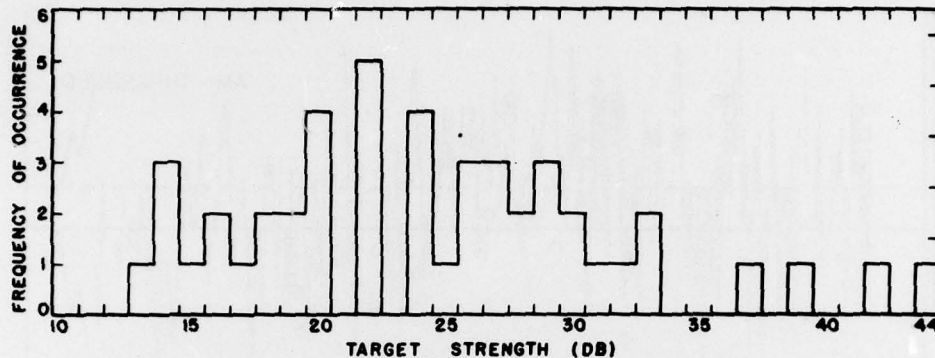


Figure 9. Target strength histogram (drift run)

the associated propagation loss. These results are presented in figure 9 in the form of a histogram. The large scatter in values probably results from the fact that the echo-ranging equation assumes that the losses are the same for the outgoing and return paths. Whereas, on the average, this is a reasonable assumption, individual losses both ways may differ considerably because about $3\frac{1}{2}$ minutes elapse between the time the pulse is transmitted and the echo received. The average value of target strength was determined to be 24.8 db with a standard error of the mean of 1.1 db. This number agrees well, with shorter range NEL measurements of 20 to 30 db,* with 25 db as measured by WHOI⁴ in the frequency range from 500-1000 cps, or with 23 db as measured by USNUSL⁵ at 750 cps.

The AM and FM threshold values indicated in figure 8 were also obtained from the echo-ranging equation. E was chosen to be the average level of those returns classified as non-echoes. This value, -39.5 db for the FM system and -33.0 db for the AM system, is an estimate of the background above which an echo must rise in order to be recognized. S , the source level at 700 cps, was 129 db, while T , the target strength, was chosen to be 25 db as determined from figure 9. When the echo-ranging equation is solved for H , the values of 93.5 db for the AM system and 96.5 db for the FM system result. If the propagation loss exceeds these values there is little possibility of obtaining echoes with the present system. In figure 8 the fact that propagation losses, over the region where echoes occurred, are generally smaller than the threshold values is to be expected, since the target strengths used to determine the threshold values are based on these very propagation losses and echoes. However, the threshold values do provide new additional information for those regions where the propagation loss falls below the threshold level. It is now evident that the reason for so few echoes at ranges greater than 176.8 kiloyards was that the propagation losses at 700 cps were too large and exceeded the threshold values. Recall also that echoes were not obtained on the AM system for nine transmissions at ranges less than 176.8 kiloyards. The average propagation loss associated with all the pulses of this group of transmissions was 95.5 db while 75 per cent of them were greater than the AM threshold level of 93.5 db. Thus high propagation loss was again the reason for missing echoes.

Before discussing the oblique run it should be noted that both of these tests on 29 and 30 October were conducted under conditions of low reverberation. The highest reverberation ever encountered was observed on 20 March 1957, when the reverberation level at 700 cps for 5-second pulses at the third convergence zone was -135.5 db.

* Reference 1, pages III-23 to III-31.

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For a 129 db source this corresponds to a signal level of -6.5 db and is 8.5 db above the highest echo level obtained in the October test. This high reverberation is not quite as discouraging as first appears. First, the example chosen is an extreme one. Second, the FM system with 10-yard resolution can reduce this reverberation by about 10 db. The 3-yard resolution on the FM system has not been adequately evaluated yet, but this could reduce the reverberation by an additional amount of as much as 5 db. Third, present plans call for an increase in the Lorad frequency to 1500 cps. It appears that the reverberation is somewhat lower at this higher frequency. The problem of reverberation is quite complex and will not be discussed further in this report.

results of oblique run

The results of the oblique run were similar to those already discussed for the drift test. More echoes were obtained on the drift test. However, the oblique run covered most of the third zone, whereas the drift test was confined to a small range interval in the zone. The target aspect for the oblique run was 248° , as compared to 270° for the drift test.

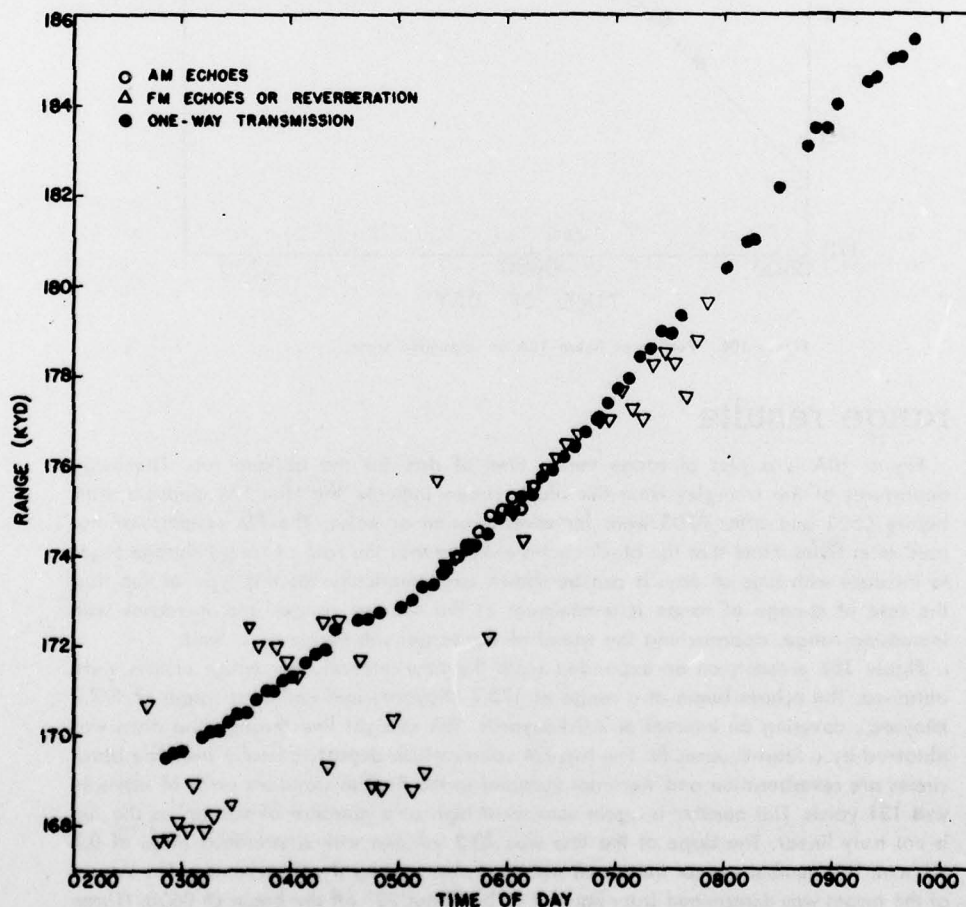


Figure 10A. Computed range vs. time of day (oblique run)

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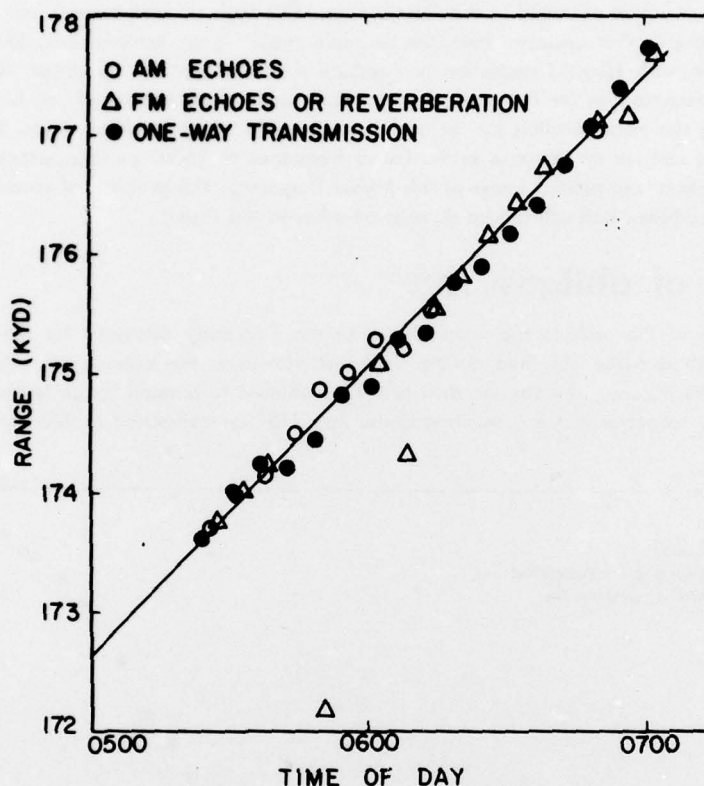


Figure 10B. Portion of figure 10A on expanded scale

range results

Figure 10A is a plot of range versus time of day for the oblique run. The large departures of the triangles from the black circles indicate that the FM measurements before 0525 and after 0705 were for reverberation or noise. The FM system was not used after 0800. Note that the black circles indicate that the rate of range change tends to increase with time of day. It can be shown mathematically for this type of run that the rate of change of range is a minimum at the shortest range, and increases with increasing range, approaching the speed of the target submarine as a limit.

Figure 10B presents on an expanded scale the time interval over which echoes were obtained. The echoes begin at a range of 173.7 kiloyards and end at a range of 177.7 kiloyards, covering an interval of 4.0 kiloyards. The straight line through the data was obtained by a least-squares fit. The two FM values which depart radically from the black circles are reverberation and were not included in the fit. The standard error of estimate was 131 yards. This number is again somewhat high as a measure of scatter, as the run is not truly linear. The slope of the line was 40.3 yd/min with a standard error of 0.7 yd/min. This number agrees quite well with that obtained by dead reckoning. The aspect of the target was determined from figure 1 to be about 22° off the beam at 0600. (Three knots times $\sin 22^\circ$ yields 38 yd/min.)

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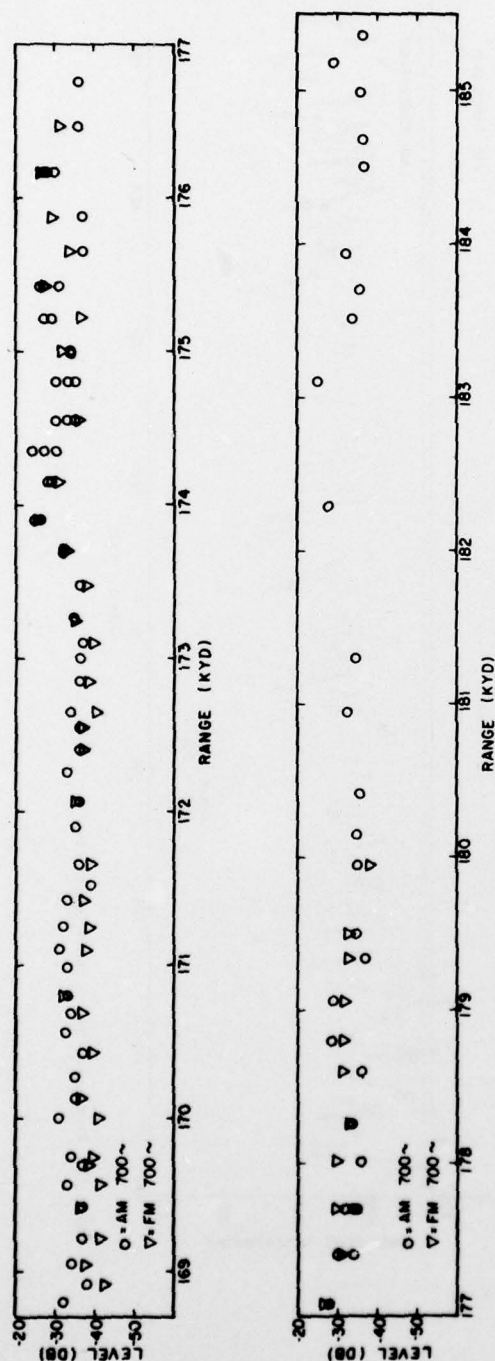


Figure 11. Peak level of returned signal vs. range (oblique run)

echo levels

Figure 11 is a plot of the highest level returned for each transmission versus range, consisting again of both echoes and background. The most significant feature of figure 11 is the rise in levels in the region from 173.7 kiloyards to about 177 kiloyards. As indicated in figure 10A, the region over which echoes were obtained was 173.7 to 177.7 kiloyards. In this interval 13 AM transmissions resulted in echoes while 4 did not. Twelve FM transmissions resulted in echoes while 2 did not. For this test the FM and AM systems achieved about the same success, 76 per cent for the AM and 83 per cent for the FM.

The FM levels at ranges greater than 177.7 kiloyards remained high despite the fact that figure 10A indicates that these measurements were for reverberation rather than echoes. The average value for non-echoes on the FM system at ranges less than 177 kiloyards was -38.0 db with a standard error of 0.5 db, while the corresponding value at ranges greater than 177 kiloyards was -32.7 db with a standard error of 0.9 db. A t -test indicated that the -38.0 -db value was not significantly different from the value of -39.5 db obtained for the drift run. However, a t -test indicated that the -32.7 -db value represents a highly significant increase in reverberation level. In contrast, the AM background levels were substantially the same at ranges less than or greater than 177 kiloyards. A careful examination indicated that the high background level on the FM system was caused by bottom reverberation from the AM transmissions. The dashed line in figure 2 indicates the transmission path at about 0700. The seamounts Y and Z are in a location such that the AM reverberation returned from the seamounts continued to arrive at the BAYA during the time that the FM system was recording possible echoes from the third zone.

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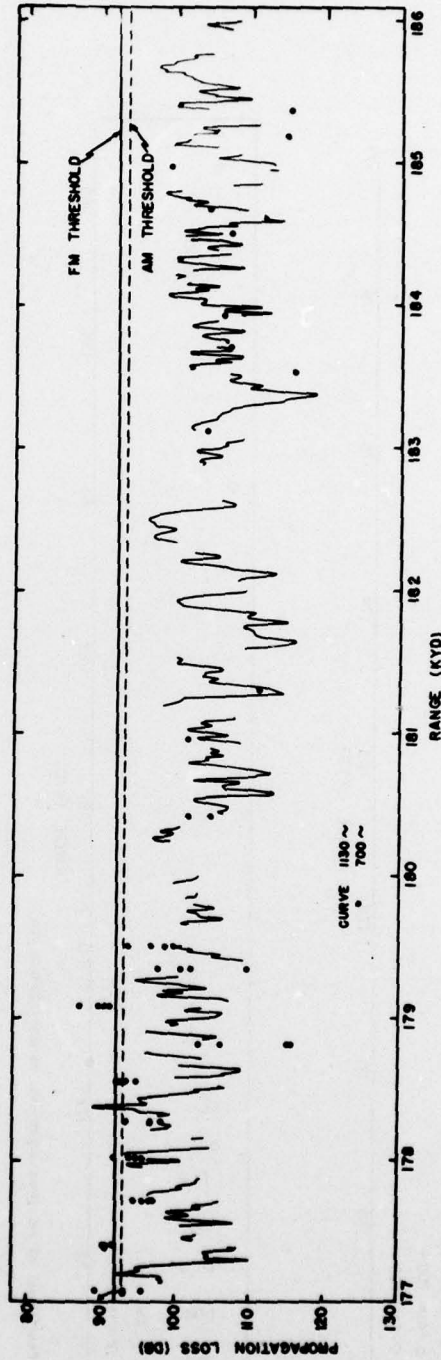
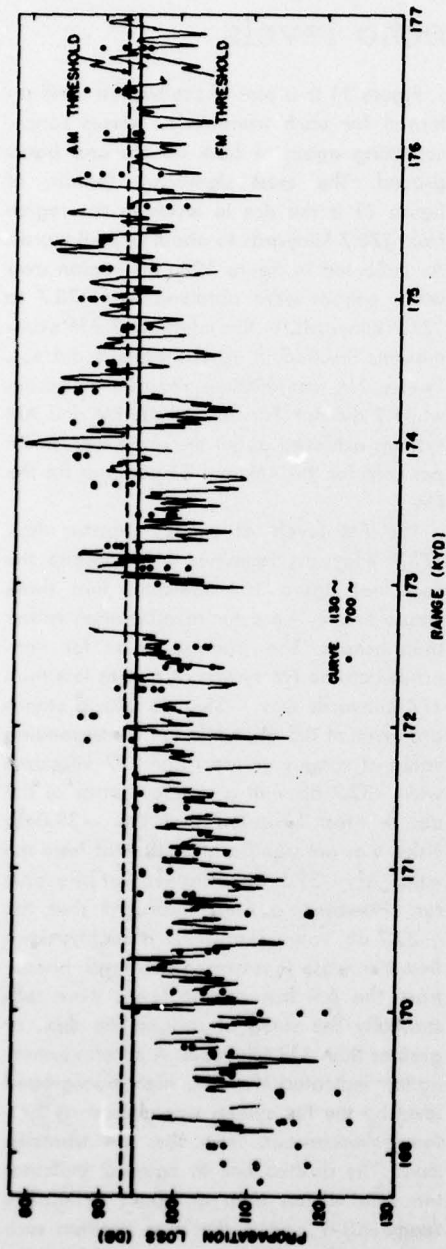


Figure 12. Propagation loss vs. range (oblique run)

The average AM background level for this test was -35.0 db with a standard error of 0.3 db. This compares to the drift test value of -32.8 db. A t-test indicated that this is a significant decrease in level, although the reason for the decrease is not known. Hence at ranges less than 177 kiloyards, before seamount reverberation became a problem, the background for the FM system was only 3.0 db better than for the AM system; whereas for the drift test the value was 6.7 db. This change in background levels may account for the fact that the AM system was almost as successful as the FM for this test, although the FM system had somewhat greater superiority during the drift test.

propagation loss and target strength

Figure 12 presents propagation loss versus range. Signals were received at the beginning of the run and were still being received at the end, so that the third zone actually extended to both shorter and longer ranges than were covered by the run. It is evident from the plot that the region of lowest propagation loss was adequately covered. The FM and AM thresholds were based on the background levels, already discussed, and on an average value of target strength of 22 db, which will be discussed presently. The AM threshold value is 93 db throughout, while the FM value is 94.5 db at ranges less than 177 kiloyards and 92.0 db at greater ranges. Note that with few exceptions the propagation loss at 700 cps is greater than the threshold values for ranges outside the 173.7 to 177.7 kiloyard interval where echoes were obtained. There were four AM transmissions in the low-loss 4-kiloyard interval for which no echoes were obtained. The average loss for these particular transmissions was 93.5 db, about 0.5 db above the threshold value.

Figure 13 presents a histogram of the target strengths obtained for the oblique run. The average value of target strength was determined to be 22.2 db with a standard error of 0.9 db. This is 2.6 db less than the value of 24.8 db obtained for the drift run. A Student's t-test indicated that this 2.6 -db difference was significant at the 8 per cent level. This difference is to be expected since the drift test was conducted at beam aspect, while the target aspect for the oblique run was about 22° off the beam at the time the echoes were obtained.

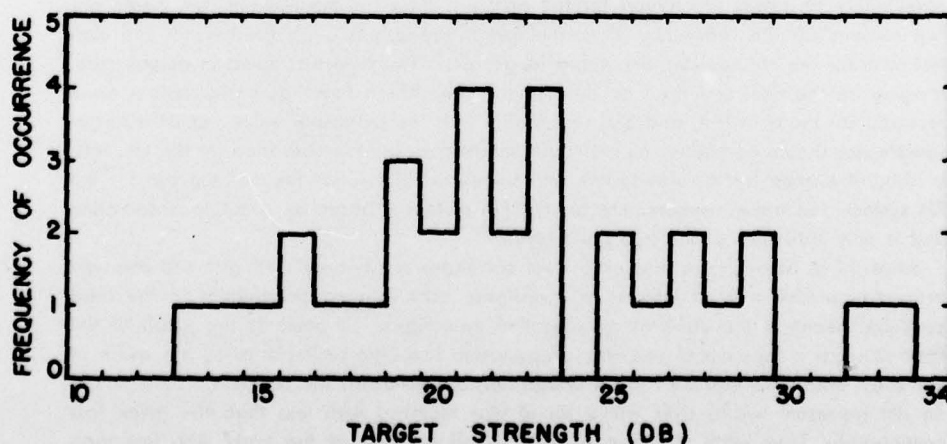


Figure 13. Target strength histogram (oblique run)

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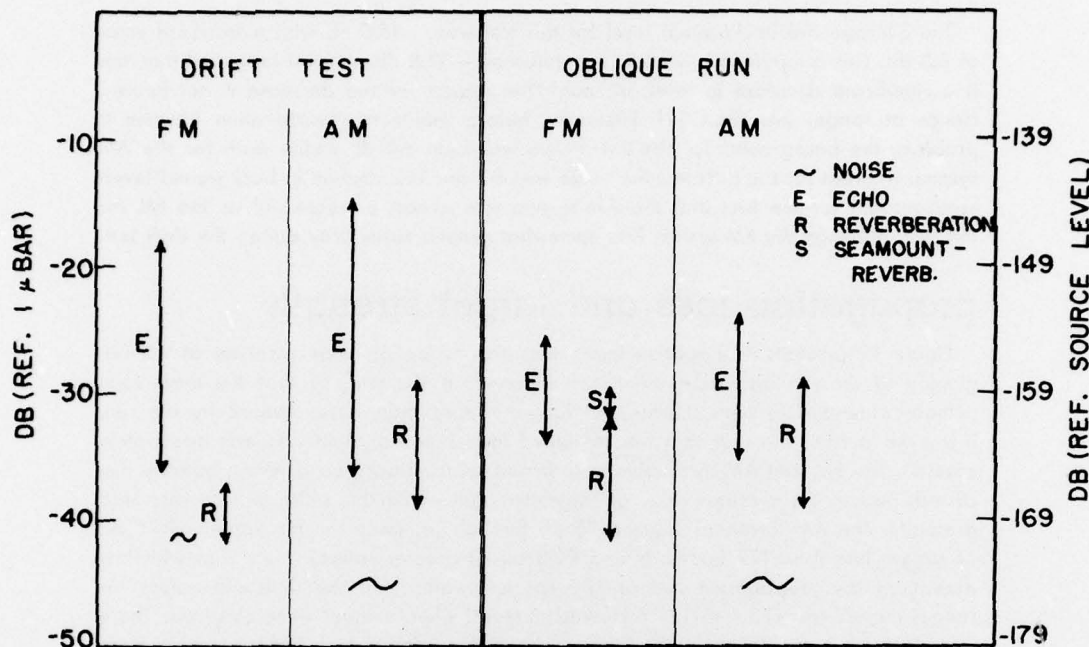


Figure 14. Summary of two tests

general discussion

Figure 14 compares the over-all results of the two tests in a simplified form. The vertical lines indicate the total range of values measured. The vertical scale on the right refers to a source level of 129 db. The chief difference to be noted is that the maximum echo levels are higher for the drift test than for the oblique run. There are two reasons for this difference. First, the target strength is 3 db greater for the drift test than for the oblique run. Second, a longer period of time was spent in actual echo-ranging on the drift test than on the oblique run. About twice as many echoes were received for the drift test, and it is reasonable that the maximum value out of a larger sample size should be higher. As previously mentioned, the reverberation for the two tests is about the same for the AM system and somewhat higher for the oblique run for the FM system. The noise measurement for the FM system is based on a single observation and is only indicative of the true noise level.

Since it has been shown that echo level correlates reasonably well with the one-way propagation loss, it is of interest to investigate echo-ranging possibilities in the third zone by means of the one-way propagation loss. Figure 15 presents the width of the third zone as a function of one-way propagation loss. The ordinate gives the width of the zone which has less than the propagation loss given on the abscissa. These values do not represent widths over which sound was received with less than the given loss continuously. They were obtained by adding all portions of the zone with less than the given loss. The 1130-cps data were obtained from figure 12. The data for 530 and 1030 cps were obtained from a third zone crossing made in 1953 in an area 300 miles northeast of Hawaii.⁶ The 1130-cps measurement for 110-db loss is somewhat too small,

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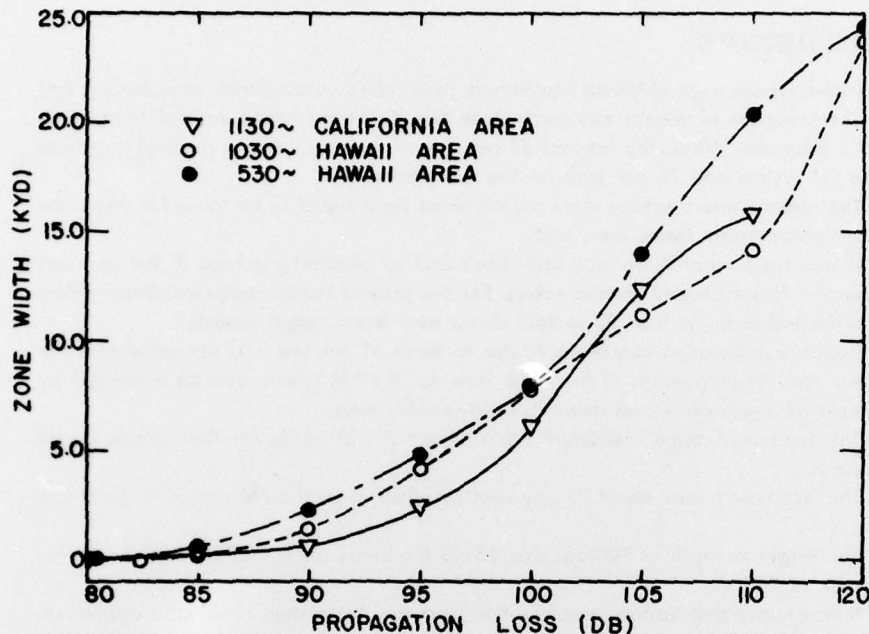


Figure 15. Third zone width vs. one-way propagation loss

as the complete zone was not covered by the run. Although the curves show considerable variability they have some features in common. All three curves begin with small slopes at the small losses, but increase quite rapidly at intermediate losses. In the region between 95- and 105-db loss the average slope of the curves is about 900 yards/db.

Before the full significance of this last result can be realized it is necessary to note a pertinent feature of the FM echo-ranging system. If the zonal reverberation is low enough for echoes to be obtained in the region of minimum propagation loss, it should be possible to obtain echoes anywhere in the zone with the FM system provided the echo level exceeds the noise or possibly the bottom reverberation. This results because the FM echoes need compete against only that reverberation which arises in the range interval in the vicinity of the target rather than against reverberation from the entire convergence zone. Since similar propagation losses apply to both echo and zonal reverberation for this range interval, the echo-to-zonal reverberation ratio should remain about the same regardless of position of the target in the zone. Thus, for each db increase in echo-to-noise ratio the effective width of the third zone can be increased by about 450 yards. (The 900 yards previously mentioned is halved because twice the one-way propagation loss enters into the echo-ranging equation.)

Work is presently underway by the Transducer Section at NEL to design a new Lorad source with a level of about 145 db. Under reverberation conditions similar to those of the present test, the effective width of the third zone should increase from 4000 to about 10,000 yards for this new source. From a practical standpoint, echo-ranging in the regions of higher loss in the zone will present some difficult problems in processing and recognition. When searching the entire zone for a possible target it may be quite difficult to distinguish echoes in a region of high propagation loss from reverberation arising from the range intervals of minimum loss, since the amplitude of these echoes may be expected to be below that of reverberation from low-loss range intervals.

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conclusions

1. Lorad echoes were obtained consistently in the third convergence zone for the first time. The reception of echoes was confined to the 4000-yard range interval from 173.7 to 177.7 kiloyards. Within this interval 83 per cent of the transmissions resulted in echoes for the FM system and 76 per cent for the AM system.
2. The regions where echoes were not obtained were found to be those for which the one-way propagation losses were high.
3. It was found that there was little likelihood of obtaining echoes if the one-way propagation loss exceeded certain values. For the present Lorad equipment these values were estimated to range from 93 to 96.5 db for near-beam target aspects.
4. Under reverberation conditions similar to those of this test it is estimated that the effective echo-ranging width of the third zone for the FM system can be increased by 450 yards for every db improvement in echo-to-noise ratio.
5. The scatter in range measurements is about ± 100 yards for the present Lorad equipment.
6. The AM system was about 77 per cent as effective as the FM system in obtaining echoes.
7. The target strength at 700 cps was 25 db for beam aspect (270°) and 22 db for an aspect of 248° .
8. It was found that bottom reverberation from the AM system could also appear on the FM system.

recommendations

1. Conduct similar tests in the third zone with bow or stern target aspects.
2. Conduct tests in the third zone under conditions of higher reverberation with special emphasis on the use of the higher resolutions on the FM system.
3. Modify the target equipment so that the FM transmissions may be recorded to aid in the analysis.
4. Modify the pulsing schedule when there is a possibility of interference between the AM and FM systems.

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